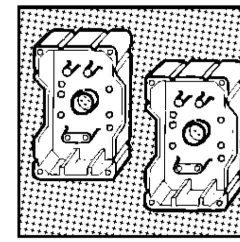
PROTOTYPING FOR DIE CAST COMPONENTS

A guide to the optimum prototyping strategies for developing and testing die cast product components

Prepared for OEM designers, specifiers and purchasers by the Diecasting Development Council

Bulletin No. 3



Prototyping is an essential stage in most product development programs. Once a design has been created to capitalize on the advantages of the die casting process, several approaches to prototyping are available:

- Single-cavity prototype die
- Gravity casting
- Rapid prototyping
- Plaster molding
- Machining from similar die castings
- Machining from wrought and sheet stock

This bulletin discusses these alternative prototyping processes and the factors involved in selecting the optimum prototyping approach for eventual aluminum, magnesium, zinc or ZA die casting.

Prototyping strategies for eventual die casting can be developed that will meet cost and time constraints and generate data that will be valuable in validating the component design. In order to select the optimum prototyping process, however, the designer must first understand die casting alloy and process characteristics and how the available prototyping processes and their alloys affect material properties.

1. Effects of Alloy and Process

Rapid solidification and cooling, high liquid metal pressures, and turbulent metal flow associated with die casting develop characteristics in the castings that cannot be duplicated by other methods. Four of the most important variations are outlined here.

- **Skin effect.** The exterior of a die cast section, to a depth of approximately 0.020 in. (0.5 mm), is dense and free of porosity, with somewhat superior mechanical properties.
- **Internal porosity.** The center (core) of a die cast section may contain porosity due to air that is mixed with the molten metal when it is being injected.
- **Mechanical properties**. Die casting imparts a unique combination of mechanical properties. One or several properties may be approximated by other methods, but some properties of the prototype will differ, some significantly.
- **Chemical composition.** Alloys used for die casting are not usually suitable for the gravity casting or wrought and sheet alloys often used in prototyping. The chemical compositions are different, causing some variations in properties.

Some properties are independent of process, or nearly so. Modulus of elasticity is nearly uniform for all alloys of a metal whether die cast, gravity cast or wrought. The density of die castings is slightly lower than that for other processes, due to entrained porosity, but the difference is usually insignificant. Other properties vary with process, some significantly, due to differences in solidification rate and subsequent forming operations.

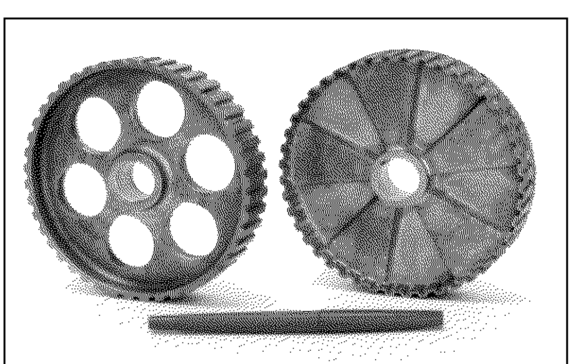


Fig. 1. The prototype sprocket (left) was cast in a plaster mold from a master modeled from the original iron part. After gravity casting, teeth were machined. When tests verified the durability of the teeth, the sprocket at right, optimized for die casting, was die cast to tolerance in the final zinc-aluminum alloy.

2. Die Cast Prototyping Processes

The only certain way to fabricate a prototype with 100% of the properties of a die casting is by actual die casting in the designated alloy. This is often feasible when a change to a different die casting alloy is contemplated.

Prototypes may be cast in existing dies using the new alloy if the die casting machine to be used is compatible with the previous machine and the dies will fill properly with the alternate alloy.

The majority of product design programs for die casting involve either a totally new design or redesign from another process. New dies are thus required, which involve the tool-

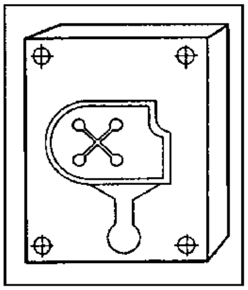


Fig. 2. A single-cavity die casting tool (above) is often used for prototyping for very high-volume production and testing before a final set of multi-cavity dies is produced.

ing costs and lead times that are associated with the die casting process.

Single-Cavity Prototype Die

The best approach to die cast prototyping for comprehensive testing is creation of a single-cavity die casting die. Surface finish and all other characteristics can be precisely evaluated. The cavity insert of this die can then be used as one of several inserts in a multiple-cavity die for final volume production.

While the time for initial prototyping is increased, production time for construction of the final dies and secondary trim tools will be shortened. Secondary tools are not normally built until production castings are available.

With this approach it is practical to make a limited range of alterations in the original die design after prototype parts are produced.

Where important design questions must first be resolved or lead times are not available, alternate means must be used that conserve money and time and produce prototypes with essential characteristics approximating those of the die cast end product. Die casting alloys are not generally suited for use with other processes and carefully selected alternate raw materials must be substituted.

Three of today's most commonly employed prototyping alternatives are: 1) gravity casting, with or without rapid prototyping, 2) machining from previous die cast shapes, and 3) machining from wrought or sheet stock.

Gravity Casting

Gravity casting, including investment casting and plaster molding, is the method most often used to fabricate die cast prototypes. Gravity casting is economical for small quantities and lead times are relatively short.

Sand molds can be used with an alloy that develops the desired properties, usually followed by subsequent processing such as machining. The castings are sometimes heat treated to bring properties such as ductility or yield strength closer to that of the die casting.

The zinc die casting alloy group (Zamak 3, 5 and 7), containing 4% aluminum, are very sensitive to solidification rate. Since strength and hardness of gravity castings are substantially lower than die castings, these Zamak alloys are inappropriate for prototyping by gravity casting, except for decorative components where mechanical properties are not important. Otherwise, ZA alloys are used.

The differences in mechanical properties, particularly tensile strength, decrease for ZA-8, ZA-12 and ZA-27 with increasing aluminum content (8, 11 and 27% respectively). The strength and hardness of ZA-27 are essentially the same whether die cast or gravity cast, so that ZA-27 gravity castings are used as prototypes of ZA-27 die castings.

Foundries experienced in gravity casting of aluminum or zinc alloys can adapt to ZA alloys. However, ZA-12 and 27 require some distinctly different techniques. ZA alloy suppliers can provide technical prototyping support to gravity casting foundries in metal handling and mold design techniques for ZA-12 and 27.

Magnesium sand castings are being routinely produced for magnesium die cast prototypes (see Section 3, Magnesium).

The major limitations of gravity casting processes are dimensional precision, minimum wall thicknesses and fatigue strength. Gravity castings require extra stock and finish machining on features when very close dimensional precision, achievable by die casting, is required. Gravity casting can reproduce many of the wall thicknesses normally required, except for the very thin walls achievable only in die casting production. If it is not practical to reduce wall thicknesses by machining, their effects must be factored into the analysis of test results. Gravity castings generally exhibit higher fatigue strength than die castings, due to lower porosity.

Rapid Prototyping (RP)

New rapid prototyping processes, such as stereolithography, laser sintering, and fused deposition modeling, are now producing economical investment cast and plaster molded prototypes. RP techniques are making possible more timely and accurate evaluation prior to construction of complex die casting dies.

With stereolithography, which uses direct input from CAD or solid modeling databases, a laser cures and hardens successive layers of liquid photopolymer. A solid plastic model can be created in a matter of hours. Atomized arc spraying of the model with a specialized molten metal results in a mold ready for use in producing an investment cast prototype.

Plaster Molding

Plaster mold (PM) gravity casting provides a surface finish similar to a die casting, with

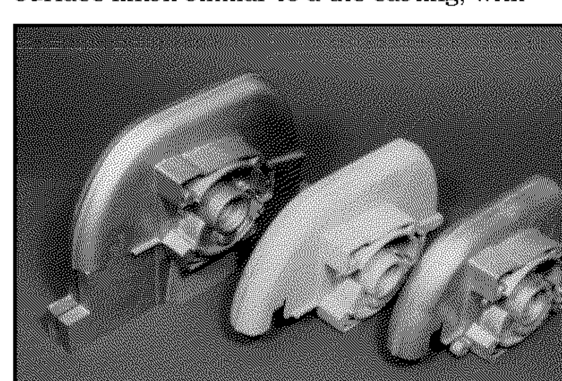


Fig. 3. The aluminum die casting at right was first prototyped as the plaster-molded aluminum casting in the center. The original pattern used to create the intermediate plaster mold tool is on the left.

thinner walls than possible with sand casting. PM is being used for prototyping with aluminum, magnesium, zinc and ZA alloys.

The plaster mold process begins with a pattern from which an intermediate rubber tool is produced. Plaster molds are poured from the rubber tool, which tolerates a variety of pattern materials. Wood masters are being replaced by the patterns produced by rapid prototyping technology. A pattern can also be made quickly by modifying an existing plastic or metal component with wax.

Magnesium alloys can react with plaster molds; therefore special techniques have been developed to make this Mg prototyping process safe and reliable. When several stages of prototyping with successive changes are anticipated, it may be advisable to make the first stages from an aluminum alloy and cast only the final design in magnesium alloy.

Machining from Similar Die Castings

Prototypes may be made by machining from die castings of similar size and shape. Prototypes of small components can sometimes be machined from heavier sections of large die castings. There are two limitations to this process.

- The size and shape of the prototype is limited by the size and shape of existing die castings.
- Machining removes the dense surface skin which uniquely characterizes a die casting.

The process is useful, in spite of these limitations, particularly when many prototypes are required and automatic machining processes are available to fabricate them. It is well suited to prototyping small gears and screw machined products for die casting.

Machining from Wrought or Sheet

Prototypes for die casting may be machined from a number of sheet and extruded aluminum and magnesium alloys. However, wrought and sheet materials exhibit relatively high ductility compared with die castings, and sometimes very low compressive yield strength. Properties may also be directional, according to the direction that the sheet or extrusion was formed.

3. Selecting the Optimum Cast Prototype Process

The optimum prototype casting alternative to a single-cavity die casting die depends on the alloy desired for eventual die casting and the properties to be evaluated. Working knowledge of the properties of die casting alloys and the available prototyping alloys is essential to selecting the optimum process.

The following sections outline appropriate strategies for cast prototyping for aluminum, magnesium, zinc and ZA die castings.

Aluminum

Aluminum die castings are readily prototyped, usually by gravity casting in sand or plaster molds. Aluminum gravity casting alloys use an alpha-numeric designation system similar to die casting alloys. The system consists of a three-digit root with a letter prefix, a one-digit suffix, or both (e.g. A332, 355.1 and A390.1).

The three-digit root indicates the major alloying elements; the prefix and suffix designate minor variations in levels of impurities and minor alloying constituents that adapt the alloys for die casting or gravity casting. This discussion will refer to the various alloys by the three-digit root only.

356 is the most frequently selected gravity casting alloy because its casting properties allow close approximation of thin walls and intricate features that often characterize die castings. Mechanical properties can be altered by heat treating the prototype to T51, T6, T7 or T71. Although the tensile and yield strengths are generally lower than die cast alloys, 356 with heat treating options meets the requirements of most prototyping programs.

When die casting in alloy 380 and resistance to corrosion is important, the prototypes can be made from gravity cast 319. These alloys have the same copper content, and the 319 prototypes will have essentially the same corrosion performance as the 380 die castings.

When die casting alloy 390 is selected for resistance to abrasion and wear, prototypes can be made from 390 gravity casting alloy.

A table, "Properties of Aluminum Prototyping Alloys," listing ultimate strength, yield strength and elongation for the prototyping alloys discussed above, is published in the DDC's OEM Sourcebook, *Product Design for Die Casting.* (See note on last page.)

Magnesium

Die castings made from AZ91B and D can be prototyped using gravity casting alloys AZ91C and E and AZ92. Properties of the gravity cast prototypes can be modified by heat treating to T4, T5 or T6 designations.

The following properties of the die casting are attainable by gravity casting: modulus of elasticity, ductility, corrosion resistance, wear resistance, sound dampening, machinability, finishing, and impact strength. Tensile strength, fatigue strength, and porosity/soundness are difficult to match. Published values of materials properties should be used to quantify the comparisons.

The introduction of high-purity gravity casting AZ91E makes it possible to evaluate the corrosion characteristics of AZ91D die castings in the gravity cast prototype. The design-

Prototyping Properties Matchup for Die Cast Parts in Zinc and ZA Alloys

	ZINC 3, 5 & 7				ZINC 3, 5 & 7	ZA-8		ZA-12		ZA-27
	Gravity Cast in:				Machined from:	Gravity Cast in:		Gravity Cast in:		Gravity Cast in:
	Specified Alloy	ZA-27 H.T.*	ZA-12	ZA-8**	Die Casting of Specified Alloy	ZA-8	ZA-12	ZA-12	ZA-27	ZA-27
Tensile Strength	−	=	=	=	=	−	−	−	+	=
Ductility	ne	=	−	−	=	−	−	−	=	+
Chrome Plate	=	−	=	=	=	=	=	=	−	=
Anodize	=	−	=	=	=	=	=	=	−	=
Wear	−	+	+	+	=	−	ne	−	=	=
Creep	ne	+	+	+	=	=	=	=	=	=
Fatigue	ne	=	=	=	=	+	ne	ne	+	+
Impact	ne	−	−	−	=	−	−	=	=	+

*3 hrs. at 610° F (320° C) and furnace cool

**Compared with fully aged properties of zinc alloys

Key to Symbols

= The property can be duplicated or reasonably approximated.

+ The prototype property will generally be superior to the die casting.

− The prototype property will generally be inferior to the die casting.

ne Relative properties have not been evaluated.

er, however, must be concerned with the chemistry of the castings as well as the chemistry of the ingot received in the foundry.

It is especially important that the foundry use protective gas shielding rather than fluxes to prevent oxidation of the molten magnesium. Fluxes can become mixed with the metal, promoting corrosion in the casting.

One magnesium supplier recommends the following when AZ91E is specified and corrosion resistance is important: 1) Specify high purity AZ91E per ASTM B93; 2) Specify ASTM B117 corrosion performance, and 3) Enforce the specifications.

Zinc and ZA

The optimum gravity cast prototyping alloy for zinc, ZA-8 and ZA-12 must be carefully selected for material properties to simulate the properties of the selected die casting alloy.

For example, gravity cast ZA-8 exhibits approximately the same tensile strength as fully aged Zinc 3. Gravity cast ZA-27 can be heat treated to reduce strength and increase ductility, making these properties closely approach those of die cast Zinc 5 and ZA-8.

ZA-27, as noted earlier, develops similar properties by gravity casting and die casting. Therefore, ZA-27 die castings can be accurately prototyped by gravity casting in ZA-27.

The table above summarizes the prototyping properties matchups for die cast Zinc 3, 5 and 7, and the die cast ZA alloys.

Contact your DDC custom die caster or alloy supplier for more specific prototyping guidance for die casting.

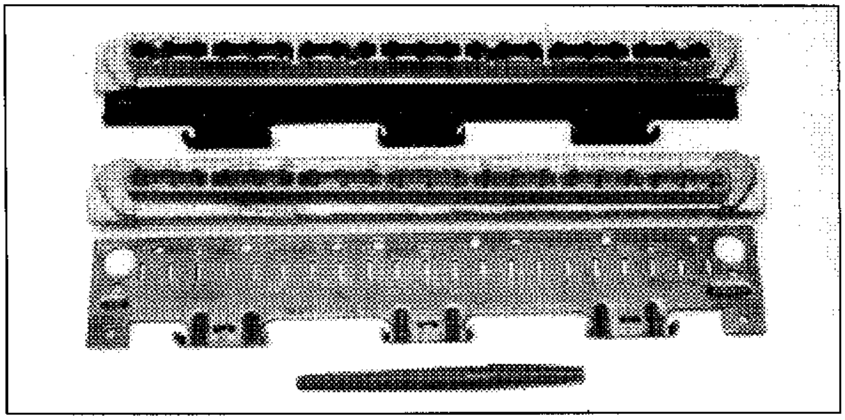


Fig. 4. The zinc die casting, shown at the top assembled to a steel stamping, was prototyped in ZA-12 using the plaster mold process. The prototype casting is shown in the center, with the unpainted stamping at the bottom.